To: SNAP Systems Engineering Team
From: Michael Sholl
Subject: Telescope rigid body sag analysis

Scope

As a part of the telescope acceptance test procedure, a final end-to-end optical performance test is planned. Because mirrors sag under gravity, the PM is expected to require a 57-actuator offloading (unweighting) mechanism. This study is intended to determine whether other mirrors require offloading, either to correct figure errors or rigid body translation. Mirror sag (both overall rigid body motion, and figure distortion) due to 1-g loading were quantified using FEM, and these results input into a raytracing code to determine effects on the PSF. Results are presented herein, and suggest that only the PM figure requires offloading. Five degree of freedom (DOF) motion of the SM is sufficient to eliminate the majority of gravitational effects (the exception is shown to be PM figure sag). SM hexapod actuator stroke requirements to eliminate the effects of gravitational sag were found to be <~250nm.

Applicable Documents:

00008-MW-02 Telescope Specification
Rigid Mirror Displacements 20050726.xls (R. Besuner)
1g mirror distortions for sholl 20050809.zip (R. Besuner)
SNAP-TECH-05023

Analysis of mirror displacement without deformation

Mirror displacements (without figure sag) due to gravity were introduced to the system, and corrected using motion of the SM. R. Besuner computed gross mirror sag during 1-g testing, and the results were input as initial misalignments into the MATLAB SNAP raytracing program. The image was adjusted using only 5-DOF motion of the SM, and a quasi-Newton algorithm. The SM was able to eliminate completely the effects of sag.

Mirror displacements (relative to the focal plane) during 1-g testing were found by Besuner to be:

	Vertex translations (μm)			Vertex rotations (μ-rad)		
	dx	dy	dz	rx	ry	rz
PM	-22.88	-0.56	34.60	0.05	-26.42	0.19
SM	-10.55	-0.12	77.63	-0.46	-14.91	0.19
FM	0.93	-0.02	35.10	-0.04	-26.42	0.03
TM	-2.65	-0.04	44.70	-0.18	-32.55	0.33
FP	0.00	0.00	0.00	0.00	0.00	0.00

The algorithm found the following corrected position of the SM:

dX	-66.24	μm
dY	-0.50	μm
dZ	-40.67	μm
θx	0.61	μrad
θy	9.44	μrad

Prior to 1-g misalignment, RMS spot size was 2.07μm. When gravity sags were applied, the RMS spot size grew to 78.1μm. Subsequent to SM correction (previous table), RMS spot size returned to 2.07μm. Conclusion: rigid body motion of the mirrors is not consequential, and offloading slings are not required.

Analysis of mirror displacement and mirror deformation

Certain modal distortions may be corrected via motion of the secondary mirror. To quantify this, mirror FEMs were analyzed for gravitation distortion. See Appendix A for computed surface profiles. Two cases were run for the primary mirror: as mounted, and with 57 offloaders. Two-dimensional, 9^{th} order polynomials were fit to the computed surface profiles, and these added to the mirror figure. The configuration was raytraced with these gravitationally-distorted PM, SM, FM & TM surfaces, and corrected using the secondary mirror algorithm. Results were as follow:

Case 1: Included PM with 57 offloaders, SM and TM

Initial spot size: 86.3μm, final spot size: 3.26μm. SM stroke required:

dX	-72.11	μm
dY	-0.15	μm
dZ	-45.11	μm
θx	0.87	μrad
θy	-2.83	μrad

Case 2: Included PM (no offloaders, SM and TM)

Initial spot size: 132.3μm, final spot size: 105.5μm. SM stroke required:

dX	-1.15	μm
dY	-0.01	μm
dZ	-42.37	μm
θx	0.01	μrad
θy	0.55	μrad

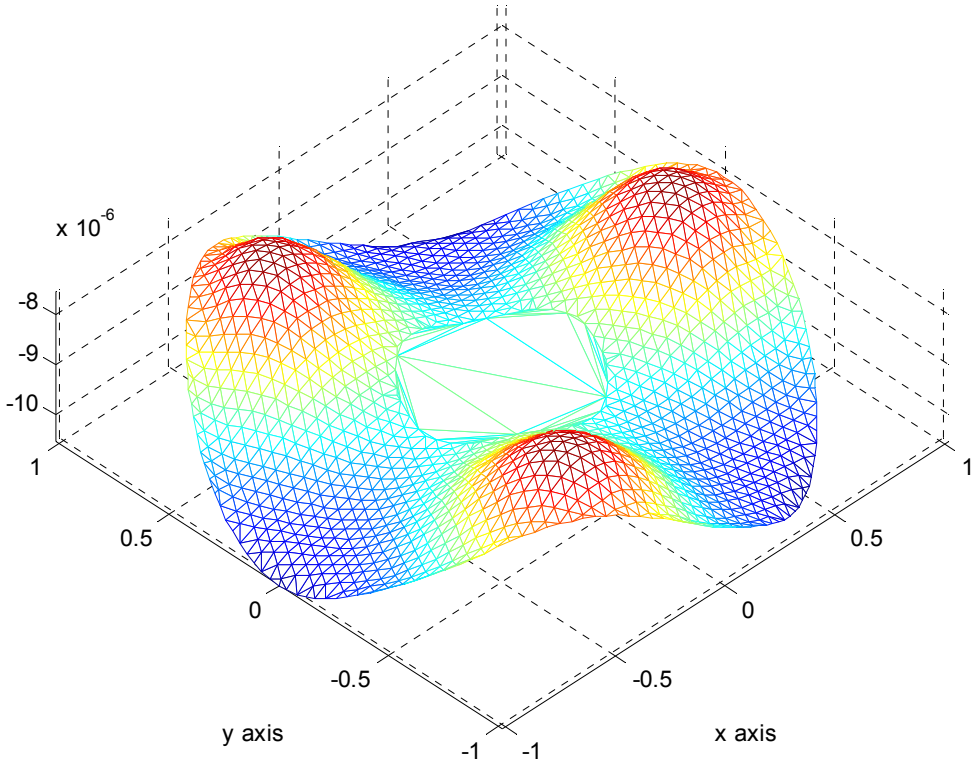
For a system capable of producing a 2.07μm geometric spot, a 105.5μm spot size is unacceptable as indication of telescope performance. Conclusion: zonal offloading of the PM will be necessary for an imaging test of the system under 1-g acceleration.

Conclusions:

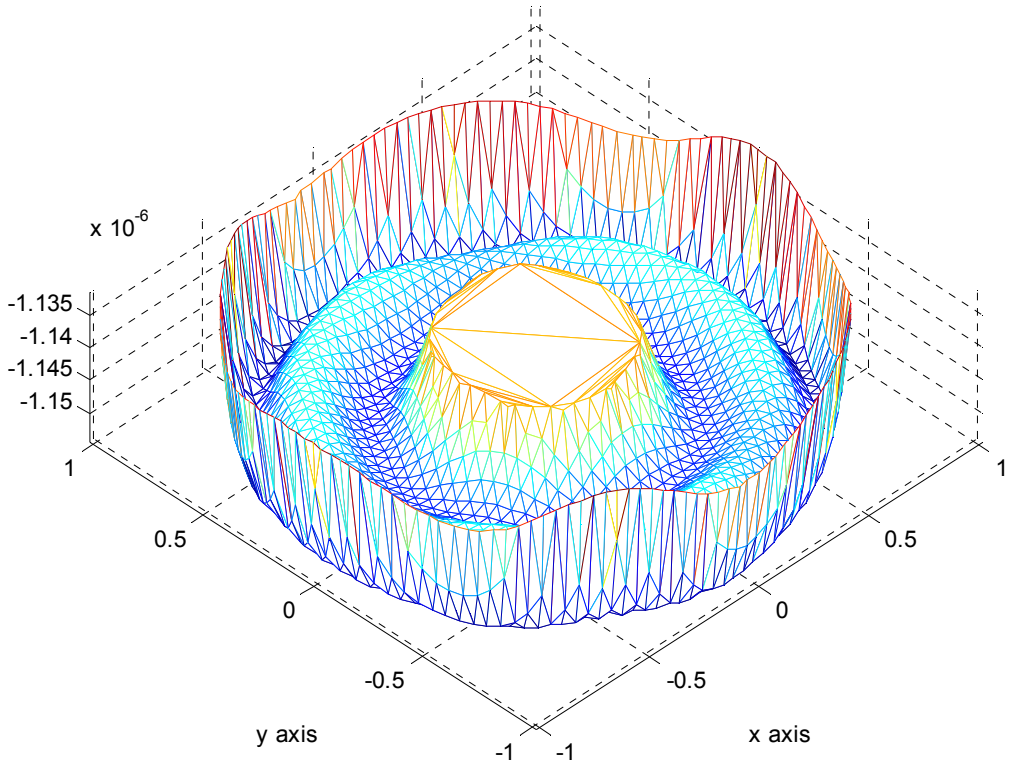
From the standpoint of WFE, individual mirrors do not need to be sling-offloaded to reduce rigid-body mirror motion. (Pupil budgets not considered in this analysis.) Five-DOF motion of the SM is necessary to achieve this.

Offloading of the PM figure is necessary in order to achieve acceptable imaging during 1-g test.

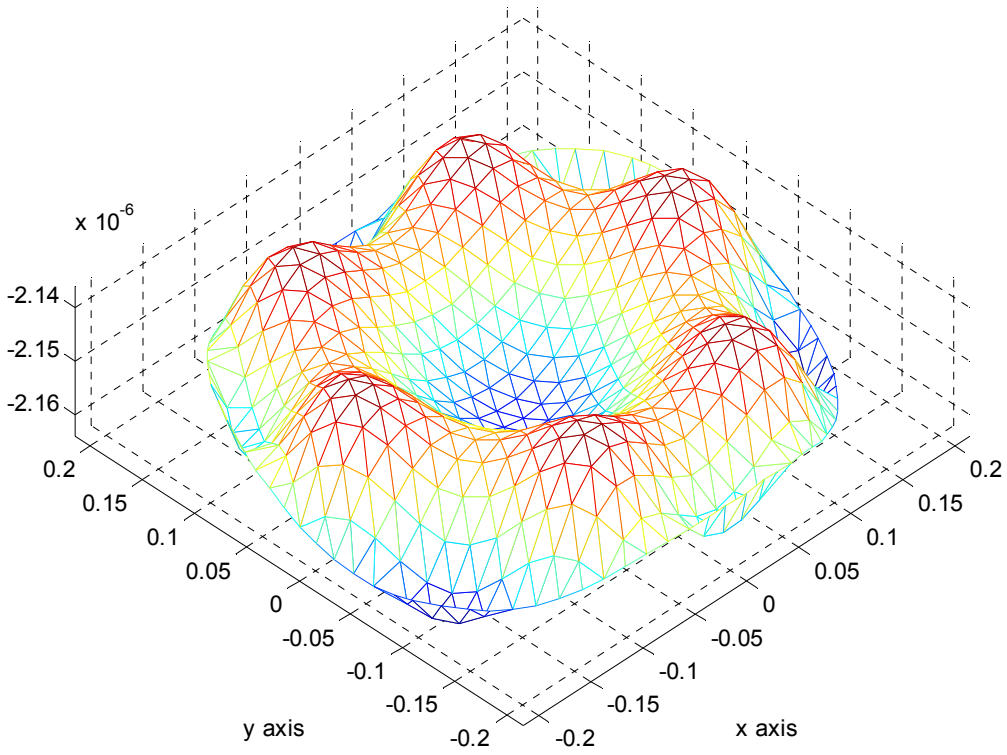
Appendix A Mirror sag data



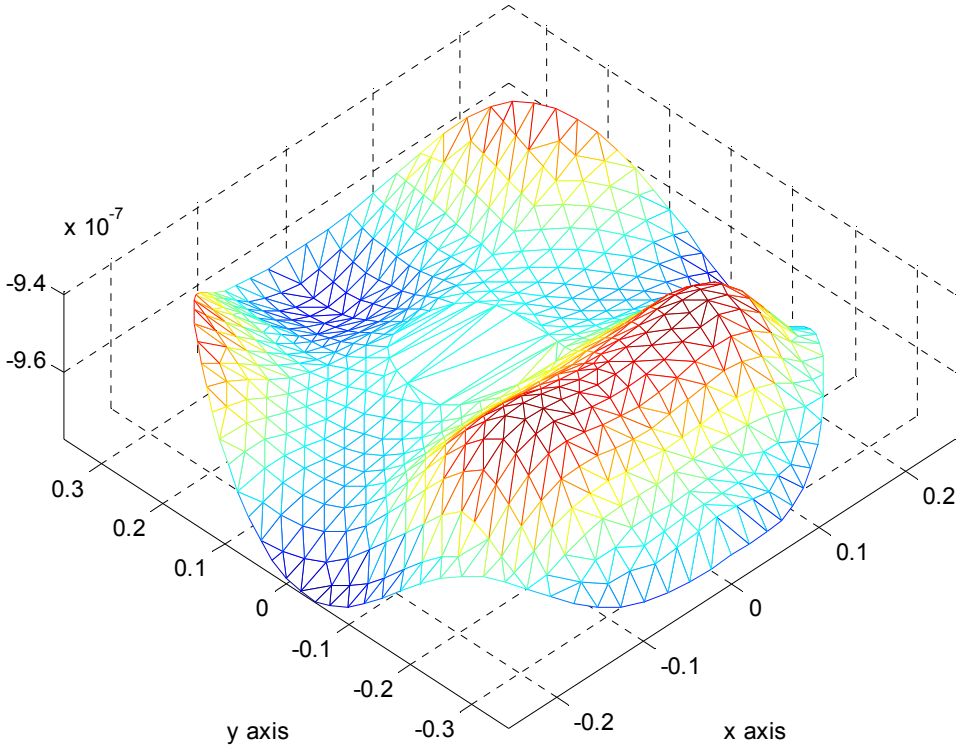
Primary mirror, no offloaders. 2.9µm P-P 0.760µm RMS



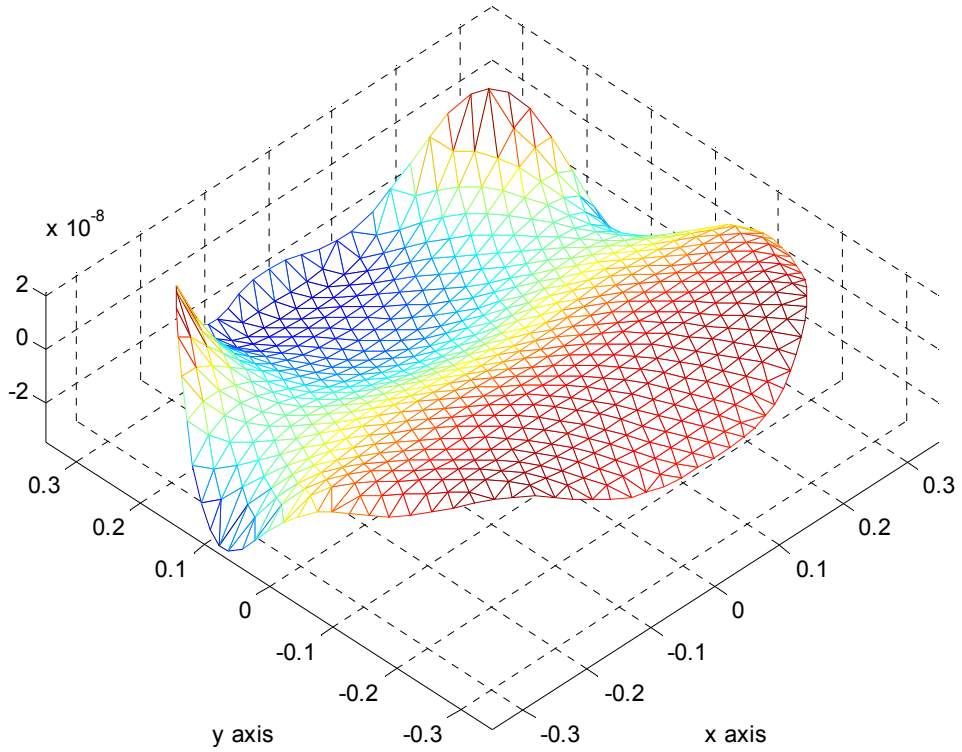
Primary mirror, 57 offloaders. 0.05µm P-P 0.0093µm RMS This mirror is mounted horizontally, and distortions are symmetric, except for the trefoil introduced by the three mount points.



Secondary mirror, 0.03µm P-P 0.008µm RMS This mirror is mounted horizontally, and the six peaks result from the inverted bipod mount.



Fold mirror, 0.039µm P-P, 0.0092µm RMS. This mirror is mounted vertically, and distortions are therefore not axi-symmetric.



Tertiary mirror, 0.088μm P-P, 0.0157μm RMS This mirror is mounted vertically, and therefore slumps in a non-axisymmetric shape.